

# **Modeling Boundary Layers and Air-Sea Interaction in the Coastal Ocean using ROMS and COAMPS**

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Award Number: N00014-04-1-0383

## **LONG-TERM GOALS**

Circulation models used for ocean forecasting in coastal regions parameterize vertical mixing using a variety of turbulence closure hypotheses. The choice of closure scheme can lead to significant differences in simulated mesoscale flows. The long-term goal of this project is to critically compare observed and modeled vertical turbulent mixing processes and the exchanges of momentum and heat across the air-sea interface and evaluate which schemes perform better, in which coastal ocean settings, and for what reasons. This comparison is being undertaken by hind-casting the circulation in the CBLAST-Low observational region during the summers of 2002 and 2003. The analysis complements CBLAST observational studies by providing a quantitative assessment of the relative contributions of horizontal stirring and advection to the detailed, yet principally 1-dimensional, vertical heat budget analyses of air-sea flux and vertical mixing observations from the Martha's Vineyard Coastal Observatory (MVCO) during CBLAST-Low.

## **OBJECTIVES**

The Regional Ocean Modeling System (ROMS), in conjunction with a high-resolution (3 km) COAMPS meteorological forecast, is being used to simulate circulation in the region encompassing the CBLAST-Low observational area. Observations from the 2002 and 2003 CBLAST Intensive Observing Periods enable evaluation of features of the model formulation and configuration that influence forecast capabilities of this geographically realistic coupled coastal ocean-atmosphere model in a region characterized by strong tidal forcing and strong diurnal heating, yet low to moderate wind-speeds.

## **APPROACH**

A high degree of realism is employed in the configuration of the CBLAST-Low regional model in order to model the regional heat budget on diurnal to several day time scales, and spatial scales of order a few km. The model has 1 km grid spacing and bathymetry from the NGDC 3-arc-second Coastal Relief Model, active/passive inflow/outflow open boundaries incorporating a bi-monthly climatology of shelf circulation (Naimie et al. 1994) and boundary tidal forcing from a model of the western Atlantic (Luettich et al. 1992). Air-sea fluxes are computed using the bulk formulae of (Fairall et al. 2003) applied to model sea surface temperature and atmospheric boundary layer values predicted by 3-km resolution COAMPS forecasts for the 2002 and 2003 CBLAST observing periods.

| Report Documentation Page  |                                    |                                     |   | Form Approved<br>OMB No. 0704-0188                  |                                 |
|--|------------------------------------|-------------------------------------|---|---|---------------------------------|
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| 1. REPORT DATE<br><b>30 SEP 2007</b>   |                                    | 2. REPORT TYPE<br><b>Annual</b>     |   | 3. DATES COVERED<br><b>00-00-2007 to 00-00-2007</b> |                                 |
| 4. TITLE AND SUBTITLE<br><b>Modeling Boundary Layers And Air-Sea Interaction In The Coastal Ocean Using ROMS And COAMPS</b>  |                                    |                                     |   | 5a. CONTRACT NUMBER                                 |                                 |
|  |                                    |                                     |   | 5b. GRANT NUMBER                                    |                                 |
|  |                                    |                                     |   | 5c. PROGRAM ELEMENT NUMBER                          |                                 |
| 6. AUTHOR(S)   |                                    |                                     |   | 5d. PROJECT NUMBER                                  |                                 |
|  |                                    |                                     |   | 5e. TASK NUMBER                                     |                                 |
|  |                                    |                                     |   | 5f. WORK UNIT NUMBER                                |                                 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Rutgers, the State University of New Jersey, Institute of Marine and Coastal Sciences, 71 Dudley Rd, New Brunswick, NJ, 08901</b>   |                                    |                                     |   | 8. PERFORMING ORGANIZATION REPORT NUMBER            |                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  |                                    |                                     |   | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                 |
|  |                                    |                                     |   | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)              |                                 |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>  |                                    |                                     |   |   |                                 |
| 13. SUPPLEMENTARY NOTES<br><b>code 1 only</b>  |                                    |                                     |   |   |                                 |
| 14. ABSTRACT   |                                    |                                     |   |   |                                 |
| 15. SUBJECT TERMS  |                                    |                                     |   |   |                                 |
| 16. SECURITY CLASSIFICATION OF:  |                                    |                                     | 17. LIMITATION OF ABSTRACT<br><b>Same as Report (SAR)</b> | 18. NUMBER OF PAGES<br><b>5</b>                     | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>   | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |   |   |                                 |

Model validation is by comparison of the simulated heat budget to time series of sea temperature and air-sea flux observations acquired at moorings deployed in 2002 and 2003 by R. Weller (Hutto et al. 2003; Hutto et al. 2005). While a strict event-wise correspondence is not anticipated without data assimilation, the total heat content, mixed layer depth, rates of surface cooling and/or heating, and mixing and entrainment at the base of the mixed layer, should be reproduced and will likely prove sensitive to vertical turbulence closure.

The ROMS model configuration for the MVCO region is being undertaken by J. Wilkin. Turbulence closure option implementation is by J. Warner. Collaboration with R. He of Woods Hole Oceanographic Institution has adjusted the tidal open boundary conditions to better fit observations through a hybrid data assimilation procedure.

## **WORK COMPLETED**

Best-estimate hindcasts of the 2002 CBLAST observational period have been completed using the Mellor-Yamada-2½ (MY25) (Mellor and Yamada 1982) turbulence closure scheme as a control case for vertical mixing option, and these results have been analyzed in detail with respect to in situ validation data from the CBLAST mooring program. Further simulations using the k-profile parameterization (KPP) (Large et al. 1994) and several options within the Generalized Length Scale scheme of (Umlauf and Burchard 2003; Warner et al. 2005) are also complete. A hybrid data assimilation system modeling system was developed to improve the phase and amplitude of the modeled barotropic tides and tidal dynamics on the southeast New England shelf by incorporating in-situ observations of tidal constituents analyzed from coastal sea level and bottom pressure gauges. The facility to compute complete momentum and tracer flux diagnostics terms in ROMS that account for the full nonlinearity of the dynamics associated with the time-varying s-coordinate system (due to the correlation of sea-surface variability, velocity, and temperature gradients in regions of strong tides) was added. This enabled exact closure of the mean and eddy heat flux transport in the vicinity of Muskeget Channel and MVCO.

## **RESULTS**

Detailed analysis of the tidal dynamics (He and Wilkin, 2006) show a strong convergence of  $M_2$  frequency tidal energy flux on the Nantucket Shoals, which produces high rates of energy dissipation 2 to 3 orders of magnitude greater than at MVCO.  $M_4$  frequency over-tides are generated in this region, and a low frequency rectified mean circulation that is subsequently balanced by Coriolis to drive the mean flow that encircles the Nantucket Shoals. With respect to the summer time heat budget, the 2002 model results show well recognized features of the regional summer circulation: warm temperatures and weak eastward flow in Nantucket Sound, cool tidally mixed waters and an associated baroclinic anti-cyclonic flow that augments the tidally-driven flow encircling the Nantucket Shoals, and strong stratification south of Martha's Vineyard. Comparisons to satellite and in situ observations show the model simulates the major features of the temperature patterns that develop during summer 2002. The evolution of the summer heat budget is characterized by three regimes: Nantucket Sound heats rapidly in June and then maintains warm temperatures with little net air-sea heat flux; tidal mixing on the Nantucket Shoals maintains perpetually cool ocean temperatures despite significant air-sea heating; and mid-shelf south of Martha's Vineyard the surface waters warm steadily through July and August due to sustained air-sea heating with only modest cooling due to the mean circulation. In the environs of the Martha's Vineyard Coastal Observatory tidal eddy heat flux emanating from Nantucket Sound

through Muskeget Channel produces a bowl of warm water trapped against the coast and significant local variability in the net role of advection in the heat budget. A suite of idealized simulations with forcing dynamics restricted, in turn, to only one of winds, tides, or shelf-wide inflows shows that tidal dynamics dominate the regional circulation.

## IMPACT/APPLICATIONS

The application of the ROMS model to estuarine, coastal and mesoscale studies continues to grow globally. The Rutgers ocean modeling group now has applications involving the both east and west North American coasts and numerous sub-domains (New Jersey coast, Gulf of Maine, Hudson River, Long Island Sound, South Atlantic Bight, Gulf of California, CalCOFI, Gulf of Alaska and Bering Sea, and more), several of which incorporate bio-optical, ecosystem, sediment, sea ice and ice-shelf sub-models into ROMS. The CBLAST model configuration has been used to illustrate the capabilities of ROMS as an operational forecast tool to assist in the deployment of moveable instrumentation, and as a synthesis tool to aid the interpretation of observations, in a series of lectures to students at International Summer Schools on ocean modeling in 2004 (Wilkin and Lanerolle 2005) and 2006 (<http://lseet.univ-tln.fr/ecoleete/ecole25eng.html>). The complete ROMS-CBLAST configuration is now distributed via links from the [www.myroms.org](http://www.myroms.org) project web site as an example application of a realistic coastal model subdomain to allow new users to gain experience with this class of application. The configuration has also been adopted by colleagues at USGS Woods Hole for sediment transport and nearshore dynamics processes projects in the MVCO region, and will be employed as a test case for fully coupled 2-way nesting in ROMS presently in development.

## RELATED PROJECTS

This project complements the extensive ocean and atmosphere observational programs and related analyses and meteorological modeling studies that comprise ONR's CBLAST-Low DRI.

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